Profile of a pioneering scientific research institute of India – Indian Association for the Cultivation of Science

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The origin, growth and decay in temporal sequence is the cycle of life process. This biological cycle may not necessarily be true in the life process of organizations, much less in the case of a scientific institution. A sound conceptual framework for the foundation, the ideas and visions of the founders, the vigour and vitality of the successors to translate the ideas into reality, adaptability to changing needs of time and environment, and, above all, contributions and achievements in the pursuit of excellence are the attributes that really make a scientific institute grow and flourish from strength to strength over the years. The Indian Association for the Cultivation of Science can claim to have all the above attributes in some measure, enabling it not only to survive a long life span of one hundred and sixteen years but also grow strong and vibrant with the passage of time.

Mahendra Lal Sircar

The early period

The Indian Association for the Cultivation of Science was founded in July 1876 by Mahendra Lal Sircar with the avowed objective 'to cultivate science in all its departments by original research and to its varied applications to the arts and comforts of life'.

From 1876 till the death of Sircar in 1904 the Association passed through a period of consolidation. The early formative years of the Association has been dealt with at length elsewhere[1].

Raman era (1907–33)

The period 1907–33 ushered in a new era of scientific research activity in the Association. This could be termed as the 'Raman era' when C. V. Raman and his associates opened up new vistas of research in physics and placed the Association at par with some of the leading institutions of the world. Raman's work in the Association on molecular scattering of light in physical optics, popularly known as the Raman Effect, earned for him and India the first Nobel prize in science (physics) in 1930. The work of Raman and his role at the Association has been well documented[2–4].

In recognition of the research work done at the Association the annual grant was increased progressively from 1926 and this enabled the activities to be extended to other areas, viz. X-rays, electron diffraction and crystal physics, magnetism and magneto-optics and electro-optics.

Post-Raman era

For the first time a whole-time research professorship of physics named after the Founder, Mahendra Lal Sircar, was created in 1933 at the Association. K. S. Krishnan, an important collaborator with Raman, was invited to assume this newly created chair. This phase of the Association (1934–1947) is marked by significant research work of K. S. Krishnan, K. Banerjee, who succeeded him, and their associates. The areas of investigations during this phase included crystal magnetism, Raman Effect, crystal optics, X-ray crystallography, etc. The work on crystal magnetism attracted the attention of the scientific world. It was also during this period that research in solid state physics was consolidated. This period saw the germination of many of the present day scientific problems of investigations. The Association became a dynamic centre of research mainly in physics during the period 1907 to 1946 under the leadership of C. V. Raman, K. S. Krishnan and K. Banerjee, who put the Association in the scientific map of the world.

C. V. Raman

The Association was housed in Bow Bazar Street premises. Initially public

Association's old building

donations and endowment were the main sustenance, but later Government of India started to provide an annual grant which was progressively increased. Since 1935 a Government of India representative found a permanent place in the managing committee of the Association. More than 430 original research papers were published during 1907–46.

The new campus

The Committee of Management of the Association realizing the urgency and need of re-organising the programmes and activities of the Association took various decisions during 1943–46. A plan formulated in 1946 envisaged the creation of an active research school where the problems of molecular structure would be investigated by the concerted team work of a band of physicists and chemists. In addition, fundamental studies in physics, X-rays, optics, magnetism and Raman effect, in which the Association had specialised in earlier years, were to continue. The plan also proposed to include investigations in physics and chemistry of high polymers.

At this juncture the Association was fortunate to have as its president, Meghnad Saha, who was a firm believer in the central role of science in national development. Saha's stewardship of the Association as hony. secretary, vice-president, president and first whole time director was at a time when two great visionaries of modern India, Pandit Jawaharlal Nehru and B. C. Roy were at the helm in the Centre and the State. This configuration resulted in Saha's setting out to give shape to a new development plan for the Association in tune with the changing needs of the time.

The old building, though historic, was inadequate to embark upon an expansion programme and a plot of land

M N Saha

measuring 9.54 acres was acquired at Jadavpur opposite Jadavpur University in 1947 on which first a research laboratory was built, and subsequently other wings were added. By 1951 the new campus was fully ready. Many research departments (viz. general physics, X-rays and magnetism, optics, theoretical physics, physical chemistry, organic chemisty and inorganic chemistry) were created between 1947 and 1951. Based on the recommendations of the three Review Committees (1958, 1968, 1983) and decisions of the Council, there has been further restructuring of the departments and currently the Association has four research departments in physics–theoretical physics, solid state physics, material science, spectroscopy; four in chemistry–physical, organic, inorganic and biological. In addition, there are three research units, two in physics (Energy Research Unit and that of the Mahendralal Sircar Prof. of physics), and one in chemistry (polymer). The infrastructure departments include a central scientific services, workshop, library, *Indian Journal of Physics*, besides general administration.

Physics (theory)

A good number of groups are engaged in theoretical investigations, the main thrust being on atomic and molecular collision physics.

Several ingenious mathematical techniques[5,6] have been developed to overcome enormous mathematical difficulties encountered in collision physics for decades. These techniques have been employed to solve longstanding problems. The observed capture phenomena in H^+–H scattering are explained. The ionization amplitude in e^+-ion (atom) involving two and more Coulomb waves and Glauber eikonal scattering amplitudes are exactly obtained. These techniques have become a standard tool for the international community.

IACS—New campus

In the study of atomic collision physics, knowledge of target wave functions is essential. Analytical representations of ground and excited states, including the Rydberg states of atomic targets[7], are obtained including the effects of electron–electron correlation partially. The accuracy of the wave functions is tested by calculating the basic structure properties of the atoms.

Due to the importance of atomic collision data in different branches of physics, including plasma diagnostics, a large number of investigations to predict the scattering parameters in e^--atom and ion–atom scattering have been carried out. Our predictions[8] on charge-transfer processes in ion–atom scattering are worth mentioning. The scattering of electrons by molecular targets is far more complicated than the corresponding cases of atomic targets. Elaborate and *ab initio* methods have been employed to predict scattering parameters for different molecular systems[9]. These results are definitive in nature.

The multiphoton and photon-induced atomic and molecular collision processes are of great astrophysical interest. The study on resonance two-photon autoionization and resonant $(n+1)$-photon ionization of H_2 has been done using elaborate theoretical methods[10]. The non-resonant discrete and continuous resonance two-photon dissociation of the polar diatom HD^+ have also been investigated[11]. These investigations have revealed the important dynamics of the multiphoton processes. A new novel method[12] has also been developed and applied for the study of doubly excited autoionizing states of the atom. Apart from these studies, photo-ionization and photo-detachment of two electron targets have been investigated with definitive results[13].

After the pioneering measurement in the early eighties, atomic collisions in presence of an external laser field have attracted a great deal of attention from theoreticians. Investigations on charge transfer processes in ion-atom[14] and e^+-atom[15] scattering stimulate the works along this line. Investigations[16] on elastic, excitation and ionization processes in laser-assisted electron-atom scattering, with and without exchange and dressing effects, have enriched the literature.

After the discovery of the mono-energetic positron beam in the early seventies, positron–atom collision physics emerged as a separate branch of science. Our physicists have contributed significantly in its maturity. They initiated the studies on: i) ionization processes[17] in $e^{\pm}$-atom scattering, ii) rotational and vibrational scattering[18] in e^+-molecule scattering, and iii) e^+-alkali atom scattering[19]. The works on e^+-atom scattering[20], including the effect of short- and long-range correlation, have created a great impact in the international community.

In the domain of particle physics, investigations[21] suggest that neutrino matter is characterized by a lepton number-violating phase at sufficiently high densities. The effect of zero gauge field modes has also been investigated[21] using Monte Carlo simulations of the lattice QCD.

Recent years have witnessed some renewed interest in the polaron problem mainly because the polaronic effects have been observed in lower dimensional systems such as in inversion layers and hetero junctions of polar semiconductors which are of much practical interest. Several calculations[22] relating this field have been performed. Moreover, electronic structure of some rare-earth elements and compounds as a function of pressure have been investigated[23] using elaborate methods predicting electronic properties like density of states, coefficients of linear specific heat, superconducting transition temperature, etc.

Physics (experimental)

Photoreaction in the crystalline state makes it possible to synthesize a large number of organic crystals useful in many device applications. The mechanism of solid state photoreaction and also its dynamic response have been investigated[24] by laser Raman spectroscopy. Crystalline state photoreaction is found to be mediated by lattice phonon through strong exciton-photon coupling in general or softening of a phonon made in the excited state of the crystal in some cases.

Importance of multiphoton processes spans areas from space physics to life science. Exciton exciton interaction and their annihilation generate an exciton of twice the energy. Biexcitonic processes in organic mixed crystals are being studied[25] by luminescence spectroscopy, revealing the exciton dynamics.

Biomaterials are finding increasing applications in many useful devices. Solid state battery, gas sensor, photovoltaic cells and optical switching device based on carotenoids, a class of materials found in some plants, have not only been developed[26] but their basic physical processes are also being investigated.

The characterization of materials is always a part of fundamental research. There are different ways to do the same. In IACS laboratory, the characterization is mainly made by X-ray diffraction and optical and electrical microscopy. A large number of materials in crystalline and amorphous forms, in the state of bulk as well as thin films and single crystals, have been studied[27], revealing the micro-structure in terms of lattice defects or imperfections which have a strong influence on its physical properties.

X-ray studies of crystal structure, structural disorders and phase transitions are the areas of intense activities[28] at IACS. Precise structural determination of organic and organometallic compounds is carried out, which led to the information about their conformation and coordination.

In separate attempts, magnetic susceptibilities, their anisotropies, specific heat, EPR, Zeeman and Mössbauer spectra of different types or rare earth crystals and some magnetic minerals are studied down to liquid He temperature to see the effect of local field and hyperfine field on the electronic and nuclear properties of the magnetic atom[29]. In the case of minerals, mixed valence states of Fe and Mn were found[30] to exhibit prominent effect on some of these properties. Moreover, EPR techniques were employed[31] to study phase transition, Jahn-Teller, magnetic dimensionality, dimeric exchange and cross-relaxation effects in suitable crystals.

In order to understand the mechanisms of the non-adiabatic decay processes, systematic studies were carried out in condensed phase with different types of perturbers and also in fluorophore itself. These studies[32] suggest that ion-pair formation, π-electron delocalization or contact CT exciplex formation between molecule and perturber are the causes for such decays in the different systems.

For its technological importance, all the major laboratories are engaged in superconductivity. The mechanism of the superconducting materials is not completely known. An unified microscopic theory of structural phase transitions, both in nonsuperconducting and superconducting materials, has also been worked out[13]. Efforts to prepare high-temperature superconducting oxides (HITSO) have brought some success[34].

Ultra-fine metal particles exhibit novel physical properties. Nanocomposites have received attention and a sol-gel technique has been developed to prepare such materials[35]. Enhanced electrical conduction has been achieved in amorphous systems by controlling their microstructure through an ion exchange mechanism[36].

Research in the areas of some important compound semiconductors like CdTe, InP and $CuInSe_2$ has been intensified. $CuInSe_2$ has been identified as one of the most promising materials for thin film photovoltaic solar cells. Achievement of 16% efficiency for InP/ITO solar cells is worth mentioning and the projection of IACS is to achieve 12% efficiencies for $CuInSe_2$ and CdTe-based solar cells by 1991. Proper emphasis has been given for the preparation and characterization of window layers[37,38] of ZnO, ITO and $Cd_{1-x}Zn_xS$ for improving the cell performances already achieved.

Hydrogenated amorphous silicon thin film and its alloys have become important electronic materials for the fabrication of low-cost solar cells and other electronic devices. Novel and state-of-the-art quality films of amorphous-Si:H and its wide band gap alloys have been developed by using plasma OVD and RF magnetron sputtering techniques[38-41]. Technology for the fabrication of amorphous-Si solar cells has been developed.

Chemistry

Research activities in the field of carbohydrate chemistry has been going on in this Institute from the early sixties. Although preliminary emphasis was on plant polysaccharides, investigations on bacterial polysaccharides were taken up a few years later with special attention to the relation between their structure and immunological specificities. Work on synthetic carbohydrate chemistry, lectins, allergens and other glycoconjugates has yielded significant results. Structures of many bacterial polysaccharides of *Klebsiella* and *Pneumoniae* types have been elucidated[42]. Several di-, tri- and tetrasaccharide moieties related to bacterial antigens have been synthesized[43] and lectins of diverse origin purified and characterized[44,45]. Immobilized lectins were used for purification of many polysaccharides and glycosubstances. Leotyping of several serogroups of *P. aeruginosa* was completed[46]. House dust allergens were separated into distinct allergy-producing and immunity-provoking components.

In contemporary inorganic chemistry the transition metals play an overwhelming role. The chemistry of these elements has been the mainstay of researches in inorganic chemistry. The mainspring of activity is the purposeful synthesis of new coordination and organometallic compounds. Structural novelty, notable reactivity and biological relevance have been the motivating factors. The control of oxidation states of metals and ligands in tailor-made environments has been the subject of prime interest[47]. Oxygen- and nitrogen-donor macrocycles and polynuclear species of 3d elements and their chemical and electrochemical transformations have received considerable attention[48-50]. In bioinorganic area, emphasis has been on modelling of biological active sites[51-54]. Possible antitumour compounds have also received attention. Considerable interest has been shown to delineate mechanisms of new reactions. These include, polyoxometallate and peroxo reagents as oxidants for organic and inorganic substrates, redox-driven isomerization, solid state structural transformation, activation of metal-carbon bond and coordinated molecules, cycloaddition reaction, etc.[55,56].

Researches in organic chemistry have as the central theme development of state-of-the-art methodologies in synthesis and application to natural product synthesis. The prime thrust in this area has been innovative and stereo-discriminated syntheses of complex carbocyclic natural products of terpenic and related origin. In the realm of synthesis these have provided the greatest challenges through the presence of a wide variety of structural features with multiple chiral centres and conformational possibilities. Recent efforts have culminated in the synthesis of sesquiterpenes from rearrangement of caryophyllene[57] and marine sources[58] and a host of complex diterpenes[59-62]. A significant outcome of these endeavours has been the development of novel protocols for carbon-carbon bond formation and functional group transformation[63], application of photo-induced and intramolecular cycloadditions[64-66], catalyst-mediated reorganization of tailor-made carbocyclic network to suit natural product synthetic targets[67] and reagents of potential and general applicability[68]. Parallel studies have also involved preparation of substituted uracil derivatives[69] and novel sulphur heterocycles[70] for exploration as medicinally useful compounds.

Significant progress has been made in the field of pico- and nanosecond photodynamics and nonlinear laser spectroscopy and linear and circular dichroism[71-75]. The photodynamical studies include elucidation of the role of magnetic field on molecular luminescence[71], geometry change, proton[73] and electron transfer[74,75] in the excited electronic states and photophysics of molecules in microheterogeneous systems (micelles[73], cyclodextrins[75] and proteins). Interesting polarization dependence and intensity distribution in the two photon absorption in multichromophoric organic molecules and lanthanide single crystals have been observed[72]. Concurrent to these experimental developments, theoretical investigations have been carried on optical bi- and multistability, optical chaos, dynamic Stark splitting, optical solitons and instability encountered in the atom-field interaction[76,77]. Work has been initiated to study supersonic jet-cooled molecules.

In the area of theoretical chemistry considerable advancement has been made in the development and application of theoretical models in inner-valence ionization processes, the studies of the intricacies of excited state potential surfaces and in unravelling the role of strong coupling in modifying the dynamics involving laser-molecule, vibrational modes and stochastic bath-modes[78-83]. Of special interest has been the delineation and understanding of the strong electron-correlation effects in the appearance of asymmetrically broadened peaks in the (e, 2e) and Auger spectrum, predicting the electron affinities of radicals and neutrals that are dominated by electron-correlation, formulation of time-dependent nonperturbative formalisms to study strong interactions (avoiding secular divergences)[78–80], exploration of methods for directly computing electron densities[81] and use of suitably tailored optimization strategies to generate potential surfaces involving real and avoided crossings (of interest in reaction dynamics)[82,83].

In the field of polymer science, researches were carried out in the areas of polymer blends, phase transfer (PT) catalysed polymerization, conducting polymers, etc. Misçible blends of similar polymers are of rare occurrence. Sustained researches have led to the discovery of several new miscible polymer blends from like polymers e.g., poly (vinyl esters)-$[CH_2\text{-}CH(OCOR)\text{-}]_n$ and polyacrylates -$[CH_2\text{-}CH(COOR)\text{-}]_n$. It was revealed that miscible blends are obtained only when the repeating units of the polymers in consideration are same in all respects except in the orientation of the ester group as occurs in the two classes of polymers[84,85]. The thermodynamics of mixing in the blend systems were elucidated by inverse gas chromatography using an indigenously made gas chromatograph[86,87]. In PT-catalysed polymerization of vinyl monomers using $K_2S_2O_8$ catalyst and quaternary ammonium salts as PT agents the existing mechanism was shown to be inadequate and additional mechanism proposed[88].

In the area of rubber chemistry novel binary systems comprising thiophosphoryl disulphide and thiazole-type accelerators which exhibit synergestic effects in the properties of vulcanizates (heat and age resistance) have been developed. Also, reaction intermediates in binary accelerator systems identified which helped greatly to understand the mechanisms of vulcanization effected by such accelerator systems[89–91].

Conclusion

Pursuit of excellence in fundamental research in physics and chemistry has been the cherished goal of the Association during its long journey. In the spectacular advancement of science during the last century and a quarter, the Association, which virtually represented the Indian science till the early decades of this century, made its humble contribution and can take pride not only in individual brilliance which it has thrown out in the early stages, but also in its institutional contribution as reflected in the current research activities briefly reviewed in earlier paragraphs. The wealth of scientific knowledge that the Association could generate through a large number of original research publications and an equally impressive number of Ph Ds it could produce stand as an eloquent testimony of a satisfying performance. But the Association has to go a long way. Success in science brings in its trail new challenges and therefore the quest for knowledge is to be pursued with renewed vigour. There is no scope for complacency.

The academic groups in the Association are conscious of their role as creative scientists. The Eighth Five-Year Plan projection of the Association reflects this mood of creativity. The endeavour continues to be enrichment of human knowledge in fundamental science, exploring the upcoming areas of 'frontier science', treading into the areas of 'high science' and 'high-tech science'. Given the necessary financial support by the Government the Association with the help of the infrastructure created and the expertise developed can aspire to become a leader in many challenging fields of basic physical and chemical sciences in the years to come.

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Regional Research Laboratory, Trivandrum, a constituent unit of the CSIR, has as its charter the following objectives:

(i) Systematic input of science and engineering research on selected and important regional resources

(ii) Continued dissemination of this knowledge to professional and possible user agencies

(iii) Systematic transfer of the feasible technologies to existing or new industries, thereby contributing to further economic development

(iv) Training and professional support for augmenting the relevant manpower infrastructure.

Such a strategy of decentralized science and technology development to meet the specific needs of a region necessarily calls for detailed planning, serious mid-course corrections, and, more than anything else, multidisciplinary team efforts.