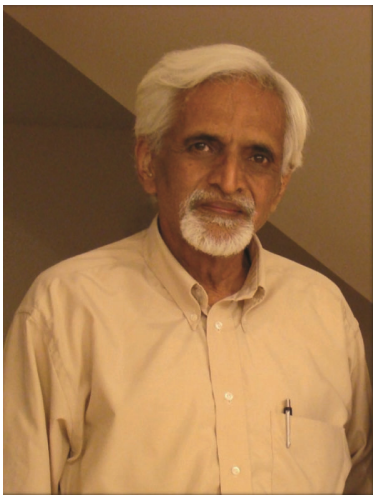
Saraswathi Natarajan Balasubrahmanyam (1932–2021)

Professor Saraswathi Natarajan Balasubrahmanyam (SNB), an eminent physical organic chemist at the Department of Organic Chemistry, Indian Institute of Science, Bengaluru, passed away on 25 May 2021 at the age of 88.

SNB was born to physician Dr C. V. Natarajan and educator Saraswathi Natarajan. The spelling of his name reflects a judicious blend of Tamil and Kannada cultures. For example, SNB took his parents name as his surname reflecting Tamil culture and the spelling 'Balasubrahmanyam' reflected Kannada culture. In fact, much ahead of his times, young SNB modified his name to incorporate the names of his mother and father. He completed his pre-university at St. Joseph's College, Bengaluru and B.Sc. at Central College, Bengaluru. While doing his undergraduate studies, SNB developed an interest in chemistry, particularly organic chemistry. His interest in organic chemistry consolidated during his postgraduate studies at Banaras Hindu University, Varanasi, from where he graduated with an M.Sc. degree with specialization in organic chemistry. Even during his undergraduate days, he was greatly influenced by the advanced learning at IISc. Young SNB used to visit IISc for working on small projects. After his PG, he joined the Ph.D. programme in the Department of Chemistry at IISc, under the guidance of Balakrishna H. Iyer (Head, Department of Organic Chemistry during 1951–1954). He was also guided by Dilip Kumar Banerjee (DKB, Chairperson, Department of Organic Chemistry, IISc during 1954–1970 and Director of the Institute during 1970–1972), a world-renowned organic chemist. That was a time when all students at IISc could be guided by any faculty. They had freedom to discuss with any professor. Reflecting the research interests of Iyer and IISc at that time, SNB worked on the modification of essential oils from sandalwood[1]. Under the guidance of DKB, SNB worked on the degradation products of abietic acid, a diterpenoid natural product[2]. After his Ph.D., SNB went abroad for his postdoctoral research and worked with Prof. Louis D. Quin at Department of Chemistry, Duke University, USA, on nicotine, a tobacco natural product[3]. After about a year and half with Quin, SNB joined Eliahu Caspi at Worcester Foundation for Experimental Biology, Massachusetts, USA, for his about a year-long second postdoctoral stint during 1961–62. His work with Caspi on oxidation of steroids resulted in six authoritative publications in frontline organic chemistry journals[4]. Subsequent to his postdoctoral stint in USA, SNB returned to IISc to take up a faculty position at which he held till his superannuation in 1992.

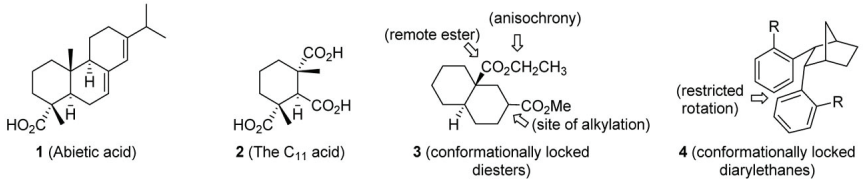


At this point, we digress to narrate what shaped SNB's future research. His formative years saw organic chemistry become an independent and indispensable discipline in science. In many respects, 1945–1990 can be termed as the golden age of organic chemistry. Organic chemists in particular and the public in general were indulging in a romantic affair with the discipline. Natural products, from being formidable problems with respect to structure determination, emerged during this time as challenging targets for studies in synthesis and properties. Many reactions, reagents, interactions with biological systems and their properties were being discovered to meet these challenges. Simple to extraordinarily complex natural products were being synthesized on a *de novo* basis. However, to meet the challenges of targeted synthesis and structure determination, in those days, physical organic chemists, working rather silently far removed from limelight, provided the much needed impetus to synthetic organic chemists. SNB was one among them. Indeed, he was trained by great organic chemists of his times, DKB (who was a student of W. S. Johnson), Quin (who developed organophosphorus chemistry into a discipline) and Caspi (who provided insights into structure and reactivity of steroidal hormones). SNB used his training and background in physics and mathematics to pursue research in the area of stereochemistry.

When SNB joined IISc, instrumentation facilities were meagre. There was only one manually operable ultraviolet and visible (UV–Vis) spectrophotometer and one CHN analyser. During his time, and due to his initiation, several sophisticated (of his time) instruments like IR, GC and NMR were inducted. SNB had a penchant for maintaining all these instruments in the Department.

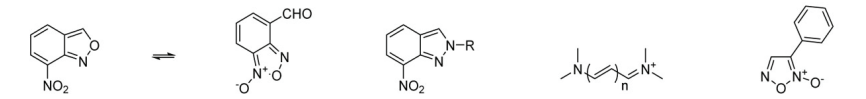
SNB started his independent work on the chemistry of degradation products of abietic acid **1** (Figure 1), a diterpenoid (20 carbons; four isoprene units) natural product isolated from pine trees (also from several other). Oxidation of abietic acid **1** with nitric acid and vanadium pentoxide provides the C_{11} acid **2**. SNB and his group designed several systems like **3** that mimic **2** to explore conformational effects and the influence of remote ester group on the stereoselective outcome of alkylation[5]. Furthermore, he delineated factors affecting the magnitude of anisotropy of the methylene protons in the ester as an indicator for its stereochemical disposition[6]. In parallel, SNB and his group studied rotational barriers in conformationally locked systems like **4** by UV[7] and by NMR spectroscopy[8].

During 1974, SNB took sabbatical leave and spent a year at the School of Chemical Sciences, University of East Anglia, Norwich, UK, by collaborating with A. J. Boulton. Subsequent to his return to IISc, SNB's group collaborated with Boulton and made notable contributions to heterocyclic chemistry, especially by exploiting the Boulton–Katritzky rearrangement involving 7-nitroanthranils **5** and furazan oxides **6** for the synthesis of indazoles **7** (Figure 2)[9]. This research led to understanding and exploitation of aminovinyliminium systems **8** for novel synthesis of pyridines and pyrimidines[10]. SNB's group worked on the conjugation of such vinamidinium push–pull systems using theoretical calculations and ^{13}C NMR spectral correlations[11]. Recently, in



1 (Abietic acid) **2** (The C_{11} acid) **3** (conformationally locked diesters) **4** (conformationally locked diarylethanes)

Figure 1. Structures of molecular entities which SNB was interested in during the initial phase of his independent research.



5 (7-nitroanthranil) **6** (4-acylbenzofurazan N-oxide) **7** (7-nitroindazoles) **8** (Aminovinyl iminium system) **9** (3-phenylfuroxans)

Figure 2. Structures of heterocyclic and push–pull systems that SNB worked on in the later phase of his independent research.

2021, he has published a paper, which turned out to be his last one, on the back donation from O to N within the N^+–O^- group in **9** caused by the combined action of mesomerism and π-polarization[12].

SNB's first article, published in the *Journal of Chemical Education* in 1960, was on the universal continuous extractor, an apparatus that can be used for continuous extraction of aqueous solutions of organic compounds with solvents heavier or lighter than water[13]. Till then (in many respects even now) a separate apparatus was used for this purpose. In his memory, we can name the apparatus as S. N. Balasubrahmanyam apparatus. He has also published an experimental procedure for the synthesis of 2,6-dicarboethoxycyclohexanone in *Organic Synthesis*, a reputed periodical[14].

Apart from the notable contributions made in the fields of physical organic chemistry, organic spectroscopy and heterocyclic chemistry, SNB has published several general articles on varied topics ranging from science and Pasteur[15], dyslexia and cultural bearings[16], Einstein, 'parachor' and molecular volume[17], brain structure and script learning[18], sunscreens[19], inclusive education[20], antibiotics[21] to wind energy for transfer of water[22]. He also wrote review articles on the life and times of DKB[23] and on abietic acid[24] in *Resonance* for generic reading.

The multifaceted scholarship of SNB is reflected in his articles linking culture, history and science. His articles on the double cone of life[25], Indian population history[26] and Indian science and technology[27] were published in *Science and Culture*, a reputed interdisciplinary journal.

Twenty-six students received their Ph.D. degrees working under the guidance of SNB. They now occupy prominent positions in academia and industry, both in India and abroad. He lived a contented life, mostly in the IISc campus, with his wife, Chanchal Uberoi, an eminent mathematician and astrophysicist (who died about two years ago). They are survived by their daughter and son, and their respective families.

Overall, the life and times of SNB coincided with the rise of organic chemistry as a central discipline in science with a wide range of implications on all beings in this universe. SNB played his part in promoting this cause.

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