The story of Nobel-winning 'quasicrystals'

The Nobel Prize in Chemistry 2011 was awarded 'for the discovery of quasicrystals' to Dan Shechtman of the Israel Institute of Technology, Technion[1]. Following the Nobel Prize announcement, there was enormous excitement among the Indian metallurgists, physicists, chemists, materials scientists and engineers. The Nobel-winning work turned out to be a topic of coffee-table discussions, particularly because it had upset an existing paradigm in the field of crystallography. The reason for its impact on the Indian scientific community was also perhaps the long-deserved recognition of years of work carried out in the Indian laboratories on these intriguing atomic structures, the quasicrystals, after Shechtman's breakthrough discovery of 1982.

The Nobel Prize reminded the world of the denial of the sheer idea of the lack of periodicity in crystals by another eminent Nobel laureate, Linus Pauling. This denial came because Shechtman's observation of such crystals was against the then existing dogma of crystallography – 'A crystal is a substance in which the constituent atoms, molecules, or ions are packed in a regularly ordered, repeating three-dimensional pattern' (as documented by the International Union of Crystallography, 1991). An Indian biochemist, P. Balaram[2] (Indian Institute of Science, Bangalore) writes in an editorial in this journal: 'The serendipitous observation of a remarkable electron diffraction pattern in a manganese–aluminium alloy by Shechtman in 1982, led to the discovery of quasicrystals, eventually transforming our understanding of the crystalline state of matter'.

Shechtman was working in a research group at the National Bureau of Standards (now known as the National Institute of Standards and Technology, NIST) in Maryland, USA, on a sabbatical, when he first saw aperiodic crystals on 8 April 1982. He had prepared an alloy of aluminium and manganese by rapid solidification and carried out electron diffraction studies. To his surprise, Shechtman found the crystals to possess the 'forbidden' five-fold symmetry[3]. The textbook knowledge until then said that crystals have order in arrangement of their atoms; the arrangements are periodic with one, two, three, four or six-fold rotational symmetries, but Shechtman 'saw concentric circles, each made of ten bright dots at the same distance from each other'[4].

Though Shechtman found aperiodic crystals while working alone in 1982, the immediate rejection from his research group during the sabbatical persuaded him to collaborate with three other researchers, I. Blech of the Technion, J. W. Cahn of the National Bureau of Standards and a French crystallographer, D. Gratias[5]. All three became co-authors of the seminal paper of 1984 published in *Physical Review Letters*[6]. However, these are not the only four (five, including Pauling) characters in the story of quasicrystals.

Shechtman was the first to report the experimental observation of quasicrystals under the electron microscope, but the theoretical diffraction pattern was provided by the British crystallographer, Alan Mackay[4] in 1982. Mackay's model was in turn based on Roger Penrose's tiling patterns. Istvan Hargittai (Budapest University of Technology and Economics), who has a keen interest in symmetry says, 'It was Mackay who recognized the importance of the pattern… . He had already published important papers related to icosahedral (that is, five-fold) symmetry. Then, for the then-hypothetical three-dimensional Penrose pattern (ordered but not periodic) he had a diffraction pattern simulated. He published this pattern and warned everybody, who would listen to watch out for such structures, because if we were blinded by the dogma that they cannot exist, we might see them without recognizing them. Thus, intellectually Mackay was a discoverer. But Shechtman made the discovery without knowing about Mackay's warning[7].'

Hargittai adds, 'Dov Levine and Paul Steinhardt, in addition to their valuable theoretical contributions, coined the name "quasicrystals", which is a very important ingredient of the story. There was a young mathematician, Robert Amman, who was not a scientist by profession, but contributed original ideas to the field[7].' Levine and Steinhardt drew parallels between Mackay's and Shechtman's independent findings. Though their publication, explaining the existence of quasicrystallinity, supported Shechtman's finding, the discovery of quasicrystals continued to be faced with opposition.

Mathematician Yves Meyer worked on geometrical structures even before the discovery of quasicrystals[8]. When he was awarded the Gauss Prize in 2010, he said in an interview[9], 'The most striking illustration is my discovery of some geometrical structures which anticipated quasicrystals. Quasicrystals were later found as specific organizations of atoms in certain alloys in chemistry.' In 1969, Meyer discovered some new configurations of points that were independently found by Penrose in 1976, and Shechtman in 1984. During the interview, Meyer also said that the positions of atoms in certain alloys exactly obey the mathematical rules he had discovered 15 years earlier.

Istvan Hargittai (left) and Nobel Laureate Dan Shechtman. (Note the pattern on their ties!) (Copyright: Istvan Hargittai, 2011.)

When one turns to the history of quasicrystals, the Indian contribution that followed Shechtman's discovery cannot be overlooked. Indian scientists relish the fact that something that was important and studied elsewhere was being worked on in India from the beginning[10]. Studies on quasicrystals were carried out at the Indian Institute of Science (IISc), Banaras Hindu University (BHU), Indian Institute of Technology-Kanpur, Bhabha Atomic Research Centre, Indira Gandhi Centre for Atomic Research and the Defence Metallurgical Research Laboratory.

S. Ranganathan[11,12] (IISc) a metallurgist who had the same Ph D mentor as Shechtman (D. G. Brandon, though in different times and places) has been working on quasicrystals since 1985. Kamanio Chattopadhyay (IISc) and Ranganathan discovered decagonal quasicrystals in 1985. P. Ramachandra Rao and G. V. S. Sastry (BHU) produced a new type of quasicrystal in Mg–Al–Zn alloy in 1985. Rao and Sastry published a paper on 'the basis for selection of alloy systems that yield quasicrystals' in an Indian journal[13], and demonstrated the validity of the basis in Mg–Al–Zn alloy[14]. The same basis was shown to be valid in the case of the Mg–Cu–Al system as well[15]. According to Sastry[14], this contribution is noteworthy because efforts prior to this after Shechtman's discovery were all aluminum–transition metal-based. These discoveries are a glimpse of the Indian contributions to quasicrystallinity. There is much more to it.

Mathematician Eric A. Lord (co-author of the book *New Geometries for New Materials*, Cambridge University Press, 2006, with Alan Mackay and S. Ranganathan) wrote an article for beginners on quasicrystals in this journal long ago[16]. When asked about his reactions to the Nobel for the discovery of quasicrystals, Lord expressed, 'There are not many applications of quasicrystals. Usually the Nobel Prize Committee is looking for something that is very useful'[17]. Balaram[2] writes in his editorial, 'New cooking surfaces and hardening steels are hardly applications likely to excite the Nobel committee'. Then what makes quasicrystals a Nobel-winning finding? 'Quasicrystals were fascinating to everybody, not just to scientists but those who read magazines and enjoy patterns', says Lord[17]. Ranganathan takes pride in saying that, 'Quasicrystals changed our knowledge about how matter is organized. It is an understanding just like understanding the structure of an atom or the structure of universe'[11].

The President of the International Union of Crystallography, Gautam Desiraju (IISc), is of the opinion that 'this Nobel Prize is all about crystallography ... it is a Prize for crystallography'. According to Desiraju, the Nobel to Shechtman also leaves a message for young researchers: 'Some of the time-tested old-fashioned values are re-emphasized by this particular Prize … . You do science for curiosity! If you are prepared well for an experiment, you see any result even though it might counter everything you have learnt before. So this Nobel Prize teaches you experimental rigour and the importance of rigour. It also tells to do your work without worrying about the predecessors'[10].

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MEETING REPORT

YETI, in Guwahati*

When I was a postdoc, I used to frequently visit webpages of Indian research institutes where I intended to apply for a faculty position. It was then that I first found out about a student ecology conference named YETI, Young Ecologists Talk and Interact (YETI is also an elusive and likely a fictitious primate). Apart from that fact that it was encouraging to see an in-house ecology conference in India, what struck me was that it is an academic event that is organized and run entirely by, and for, students of ecology. Within a few months of taking up a position at the Indian Institute of Science, Bengaluru I got an opportunity to see this highly energetic ecology student crowd when they invited me to conduct a workshop on mathematical modelling in ecology.

The idea to create such an interactive forum for young researchers of ecology was conceived among the student community of Bengaluru in 2008, which is not surprising given the city's reputation as a key centre of research in ecological sciences in India. Following the success of a small-scale event that restricted

*A report of the conference on 'Young Ecologists Talk and Interact' (YETI 2011).