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Tilings, coverings, clusters and quasicrystals

The article entitled 'Metallic phase with long range orientational order and no translational symmetry' by Shechtman *et al.* published in *Physical Review Letters* in 1984 heralded the discovery of a new and unexpected variety of solids. This variety of solids came to be recognized as a new state of matter which possessed simultaneously properties of crystals (as revealed by fairly sharp diffraction patterns) as well as those of non-crystalline solids (like glass, because of lack of periodicity) and was referred to as 'quasi-crystals'. Text books of solid state physics deal with 1, 2, 3, 4 and 6-fold symmetry that govern the symmetry of crystals. The requirement that packing of unit cells in 2 or 3 dimensions should fill space without voids rules out occurrence of all other rotational symmetries in crystalline matter; note that 5-fold symmetry is forbidden. The periodic occurrence of unit cells decorated by atoms in a variety of ways led one to understand the nature of (atomic) structure of crystals. But now the new structure of matter discovered by Shechtman *et al.* was observed to exhibit non-periodicity (that is, ratio of distances between adjacent spots in the material's diffraction pattern was an irrational number) and 5-fold symmetry, referred to as icosahedral symmetry by them. Several alloys have been discovered thereafter that exhibit icosahedral as well as decagonal (10-fold) symmetry.

A 2D flat surface can be tiled without leaving gaps/voids by using regular figures (all sides equal and all angles equal) like triangles, squares, hexagons, etc. or some combination of regular shapes; it results in a periodic pattern. However, use of regular pentagons, having 5-fold symmetry, to tile a plane results in gaps that are not pentagonal. When we move to 3D, this space can be filled by three of the five regular (all sides and angles equal and all faces identical) Platonic solids, namely cubes, tetrahedra or octahedra. But the other two Platonic solids, namely dodecahedra (12-faced solid) or icosahedra (20-faced solid) cannot fill 3D without leaving gaps. It should be noted that both these types of solids exhibit 5-fold symmetry.

Roger Penrose (Oxford University) has investigated the problem of whether a set of tiles could cover a surface without gaps but without generating a periodic pattern; he succeeded in producing 'quasi-periodic' patterns using a set of tiles – to be specific with a minimum of two different 4-sided rhombuses (all sides equal but all angles not equal) – laid according to 'matching rules', which results in a pattern that seems to be periodic but not truly so. Indeed it turns out to be a 5-fold symmetric quasi-periodic pattern. He has shown that 3D space can similarly be filled by using two distorted-cube-like shapes referred to as prolate and oblate rhombohedra. Once again this results in a quasi-periodic structure. Decoration of the rhombohedra by atoms would result in the atomic structure of the quasi-crystals observed by diffraction.

Instead of tiles/3D-shaped solids, one can think in terms of two or more clusters of atoms with interactions that mimic the matching rules. Recent studies by Steinhardt *et al.* (*Nature*, 1996) have shown that even a single type of atomic cluster can generate quasi-periodicity in structures that maximize the cluster density, without bothering about matching rules. The quasi-crystalline phase, generally considered metastable at some elevated temperature is found to occur as a stable phase at low temperature in certain alloy systems. As a function of temperature, the quasi-crystalline phase is also found to reversibly transform to a crystalline phase in some cases via a series of crystalline 'approximants'. 'A crystalline approximant is a phase whose composition is close or identical to that of a quasi-crystalline phase and whose unit cell has atomic "decorations" that looks quasi-crystalline, such as icosahedral clusters of atoms but which is nonetheless a crystal. These crystalline approximants are the missing links between periodic crystals and their quasi-crystalline cousins.' The concept of crystal approximants has played an important role in the study of quasi-crystals.

The article by Lord *et al.* (page 64) deals with various aspects of the quasi-crystalline world, especially with the cluster picture – 'which is closer to reality of the way the quasi-crystals grow'. According to them, 'whether any of the periodic set consisting of only one tile is possible is an open question'. The authors have discussed various ways of coverings of planes, triacontrahedral clusters and applications to cluster models of quasi-crystals with the objective that it may lead to a realistic model of quasi-crystal structure. The analysis of the arrangement of the triacontrahedral clusters in 3D Penrose tiling is a new concept that is being discussed for the first time in this paper.

K. R. Rao

Earthquakes – The killing seismic events

The earth is being shaken violently by earthquakes, now far too frequently. There is a pattern in the occurrence of these killing seismic events – they are related to active faults along which either one crustal block slides past another or one crustal plate slips under another. In the Himalayan province the great earthquakes (magnitude ≥ 8) are associated with the movements on the detachment plane representing subsurface extension of the thrust-faults that define terrane boundaries. Along this detachment plane the pile of Himalayan rocks has got uprooted from its foundation and become prone to displacement by the northward-pushing Indian Peninsula. The distribution of epicenters – which are confined to a nearly 100 km wide belt about 50 km south of the lower tectonic boundary of the ever-snowy Himadri (Great Himalaya) – indicate that this detachment plane lies 15–25 km below the surface. The moderately big earthquakes at Srinagar in Garhwal of 1803, at the Dharchula–Bajang area in eastern Kumaun of 1916, 1958 and 1960, at Uttarkashi in western Garhwal of 1991 and at Chamoli in central Garhwal of 1999, lie in this belt of pronounced seismicity. And this high-seismicity belt lies in the very populated terrain of the Lesser Himalaya. Uttaranchal Himalaya (comprising Garhwal and Kumaun divisions) lies in the central seismic gap where the crust is locked to its base and where no great earthquake has occurred since the 1255 disastrous even in central Nepal. Since in this segment the steadily accumulating strain has not been relaxed sufficiently, it is very vulnerable to earthquake hazard (Khattri, K. N., *Tectonophysics*, 1987, **138**, 79–92; Gaur, V. K., in *Earthquake Hazard and Large Dams in the Himalaya* INTACH, New Delhi, 1993, pp. 63–74; Chander, R. and Gahalaut, V. K., *Curr. Sci.*, 1994, **67**, 531–534; Bilham, R., *Curr. Sci.*, 1995, **69**, 101–128). A recent study (Khattri, K. N., *Curr. Sci.*, 1999, **77**, 967–972) shows that the chance of occurrence of at least one great earthquake in this seismic gap in a period of 100 years is 0.52. And it is in this sector that many high dams are being constructed, planned or contemplated. The controversial Tehri Dam is within the radius of 125 km of the Chamoli epicentre. It is therefore necessary to know when the next great earthquake that can relax the accumulated strain would occur.

The study carried out by Rajendran *et al.* (**page 45**) is an attempt to understand the pattern of the frequency and intensity of earthquakes in this vulnerable sector. The Chamoli earthquake occurred in the area of overlapping packs of rocks split by thrust faults and cut transversely by tear faults. Way back in 1976 I had recognized the NNW–SSE trending fault of the Chamoli area – which I named the Nandprayag Fault (Valdiya, K. S., *Tectonophysics*, 1976, **32**, 353–386) – as the most active fault of the region responsible for recurrent landslides and earthquake hazard. I have always looked at the NW–SE trending faults with considerable trepidation, for I hold them responsible for triggering earthquakes. The study by Rajendran *et al.* shows that it was the reactivation of a roughly E–W oriented growing fold associated with an active fault that was responsible for the 1999 event. The study is a modest – though very significant – contribution to the building up of a database on the slip rate and fault offsets, which help evaluate the recurrence rate of earthquakes. Another upshot of the investigation is that historical temples tell a lot about the history of earthquakes in this region.

K. S. Valdiya

The underground flower: Biology thy name is exception!

Biology baiting has been a common practice among the non-biologists, especially the physicists. None less than Lord Rutherford is supposed to have dismissed discussion on this branch of science by remarking that biology is but after all stamp collection. Implicit in this remark is that biology knows no rules, and respects none. For every statement made, there is evidence to the contrary. Thus a few years ago, I recall reading a paper on the discovery of a bacterium whose cell shape challenged the then generally known shape – spherical. This bacterium was rectangular! Naturally enough, physical scientists are foxed when they come across such spectacular exceptions and then rather derisively dismiss the study of biology from serious attention.

Kaul and co-workers (**page 39**) review one of such exception. They report that for every 6944 species of plants whose flowers we can see and smell there is one that also produces flowers which we cannot see nor smell because the species chooses to flower underground. These species, referred to as amphicarpic, produce flowers both above-ground and below-ground and thus seem to enjoy the best of both possible worlds – the aerial and subterranean path to reproduction. These plants are unlike the groundnut plants which bear aerial flowers but develop their fruits underground. Though the frequency of the amphicarpic plants is very small constituting only about 0.0144 per cent of the flowering plant species, it has been reported to have evolved independently several times in the course of the evolution of the flowering plants. And thus, though small in frequency, this behaviour cannot be disregarded as a chance event.

Quite obviously the underground flowers in the amphicarpic plants are completely self-pollinated and the fruits and seeds are relatively protected from vagaries of climatic fluctuations and predation. On the other hand, the aerial flowers are usually cross-pollinated bringing into the amphicarpic plant the much-desired genetic variability. Despite their exciting dual flowering behaviour, there appears to be not much work done on these species. Almost nothing is known about the evolutionary significance of these flowers. What could have driven them to flower thus? All these and more questions go abegging. As the authors mention, detailed physiological, ecological and evolutionary studies are required to fully understand and appreciate the significance of the underground flowers.

Meanwhile one thing is clear about the underground flowers – they seem to have clearly chosen their stand against the servant who remarked to his queen in one of Tagore's poem 'I will keep fresh the grassy path where you will walk in the morning, where your feet will be greeted with praise at every step by the flowers eager for death'. The underground flowers are certainly not among those eager to shower praise and die!

R. Uma Shaanker